Ontario Hydro

Memorandum To DISTRIBUTION

Date January 16, 1987

Location or Dept

File 812.2(P)

Subject **Overhead Conductor Ampacity Studies**

Attached is a Research Division report on conductor ampacity. The work started in 1985 and continued last summer. Two previous reports have been issued. The first (E85-230-H) described the instruments used to study conductor temperature and clearance. The second report (E86-91-K) validated the thermodynamic models used to predict ampacity, but pointed out discrepancies in the use of ruling-span approximations to calculate clearance.

The third report, attached here, compares predictions of conductor temperature based on meteorological observations with our observations. There are several factors applied to wind-speed data that make predictions too conservative. More accurate conductor temperature estimates can be obtained if the wind model is changed. Some theoretical support for increased wind angle at low wind speeds is identified.

Conductor ampacities will increase if improved, probability-based models of cooling are applied. The wind-direction standard deviation, which is large at low wind speeds, makes the apparent wind angle much larger than the mean direction. We should study this factor in both sheltered and unsheltered rights-of-way.

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Attach

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To: Mr. A.E. Martin
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OVERHEAD CONDUCTOR AMPACITY STUDIES III
PREDICTED AND OBSERVED CONDUCTOR TEMPERATURES
ESSA TEST LINE RESULTS, SUMMER 1986

W.A. Chisholm and J.S. Barrett
Electrical Research Department

The Bulk Electrical System contains many older circuits that have a maximum conductor temperature limit of 49°C. A program of measurements and modeling has been initiated to allow best use of these lines during summer peak-load conditions. This report describes measurements on an unused 115-kV circuit. Daytime conductor temperatures calculated from weather predictions were too high on 23 days, accurate within 2 C° on 8 days and too low on 5 days. The conservative bias is reduced if improved wind models are used.

INTRODUCTION

Many older lines in the Bulk Electrical System were designed and constructed for low maximum operating temperatures. At that time, designers thought that an undesirable annealing process would occur if conductor operating temperatures exceeded 49°C. The annealing temperature limit is now known to be higher. However, clearance requirements to ground still limit the safe and economical operation of these lines. The problems are particularly acute in summer conditions. High ambient temperatures combined with low wind speeds or high solar input lead to reduced clearances and restricted power flows.

job	file	date	report no.
17-145-202-31	812.2	February 9, 1987	86-360-K

In previous work/2-3/, we initiated a program of continuous data measurement. A 115-kV single-circuit line was energized with a circulating current from a 100-kVA 230-V transformer. The program then developed instrumentation for the following parameters:

- Conductor Temperature, 0-100°C, accuracy ±0.5°C.
- Ambient Temperature at Conductor and Ground Level, 0-50°C, accuracy ±0.3°C.
- Wind Speed and Three-Axis Direction, 0-25 km/hr, accuracy ±0.2 km/hr at low speeds.
- Input Solar and Reflected Radiation, 0-1500 W/m^2, accuracy ±40 W/m^2.
- Conductor Current, 0-300 A, accuracy ±2 A.
- Clearance to Ground of Two Spans, 0-10.6 m, accuracy ±0.04 m.

As in previous work, a portable computer logged the data onto microcassettes. A larger computer was used for subsequent analysis. Resource Utilization stored their temperature and wind-speed predictions for the test site during the summer. This data was then transferred by 9-track tape to our computer, which eliminated tedious re-entry of individual observations. The weather data and known circulating current provided input to the Transmission Design ampacity prediction method /4/. This report compares the predictions and measurements. A future report will describe further results relating the conductor temperature to its clearance.

INSTRUMENTATION IMPROVEMENTS

The instrumentation has been described in detail previously/2/. Hot-wire type anemometers measure wind speeds with good low-speed resolution. A thermocouple, placed under the outer layer of aluminum, measures the line-conductor temperature. Ambient temperature is sensed with a semiconductor at the conductor height and is also recorded at ground level in a Stevenson (meteorological standard) screen. A current transformer records line current. Silicon photocells monitor the solar input. Line clearance to ground is determined with a sonar-based rangefinder.

Recommendations for improved reliability in a previous report/3/ were implemented. Twice as many wind speed, solar and ambient temperature sensors were used. An electrically-isolated thermocouple amplifier was installed. Steel plates were leveled on the ground to ensure good sonar reflections for the rangefinders.

The solar instrumentation was changed from previous studies. Solar input to the conductor is usually determined with instruments such as pyrano-albedometers that measure incident and reflected radiation to a horizontal plane. However, conductors are round and will accept solar input when the sun is low in the horizon as well as when overhead. We constructed two circular solar input sensors from silicon photocells. We calibrated these sensors against a pyrano-albedometer by aligning the reference instrument at 90° to the sun's rays.

In addition to storing the 15-minute averages of all measurements, the standard deviations were computed and recorded in each sampling interval. These standard deviations helped in the identification of erratic readings. They also provide better data for probability-based estimates of conductor temperatures.

The equipment was installed on July 3 and was removed on September 11. In the first two weeks, some timing problems with the A/D converter at high temperatures were identified and resolved. The forty days of valid measurements produced 150,000 direct observations. These data were supplemented with ground temperature and wind speed results from Resource Utilization - Meteorology instruments. Out-of-Limits Monitoring (OOLM) temperature and wind-speed predictions for the Barrie area grid square were also retained for our studies.

EXPERIMENTAL RESULTS

The data were processed and are shown in Appendix 1, Figures A1-A12. Each Figure shows three days of observations. Solid lines show the incident solar radiation, the vector sum of horizontal and vertical wind speed, the ambient temperature at the conductor height and the conductor temperature. The line current was a constant 260±10 A and is not plotted. The grey areas appearing around the measured data indicate the 15-minute standard deviations. These uncertainties are large for many solar and wind observations, and small for temperature data.

Dashed lines in Figures A1-A12 show the OOLM 1-hour and 5-hour predictions of wind speed and ambient temperature. The existing practice for solar input assumes that the sun provides a constant 814 W/m^2 to the conductor. This model was modified by turning the sun on at 6AM and off at 8PM. With predicted values for ambient temperature, wind speed and solar input, the Transmission Design Method for ampacity calculations/4/ was used to calculate 1-hour and 5-hour predicted conductor temperatures. These temperatures are plotted as dashed lines in the bottom graphs of Figures A1-A12.

The highest reliable ambient temperatures were recorded on July 6 between 2 PM and 5 PM. While the ambient was 34°C, the wind speeds were high and the conductor temperature only reached 40°C. Other periods had lower ambient temperatures but slower wind speeds, leading to conductor temperatures of 43°C on several occasions. At no time did the severe conditions of the 1985 season (30°C, high solar and low wind, leading to conductor temperatures of 47°C) appear in the 1986 results.

MINIMUM WIND SPEED STUDIES

In a study of natural-wind cooling of conductors at low wind speeds, Morgan/5/ points out that the wind direction is varying continuously. For flat areas, a standard deviation of 5-10° contributes slight additional cooling. The extra cooling effect of wind shifts is more significant in sheltered parkland or urban areas, since standard deviations of wind direction fall in the 15-60° range. Thus, it is somewhat pessimistic to assume that the wind angle to the conductor is always 20°. Figure 1 from Morgan/5/ shows the desirable influence of wind direction standard deviation on the cooling of a conductor.

Existing Ontario Hydro practice sometimes limits the minimum wind speed to 4 km/hr instead of 0 in ampacity calculations. The limit was applied to correct for negative ampacity predictions from the ampacity models. Instead of adjusting the wind speed, however, the wind angle should probably be made a function of wind speed, with lower velocities leading to higher wind angles.

We checked the influence of a minimum wind-speed assumption on the predictions of test-span temperatures. Consider the predictions of conductor temperature based on a minimum wind speed of 4 km/hr. We assume that the wind angle to the conductor is 20°. Reduction factors for spatial variability and sheltering of adjacent trees are also applied to the wind speed. The net result is a minimum perpendicular wind velocity given by Equation 1.

$$V_{90} = K_h K_z V_{wind} \sqrt{0.05+0.95\sin^2\theta} \qquad (1)$$

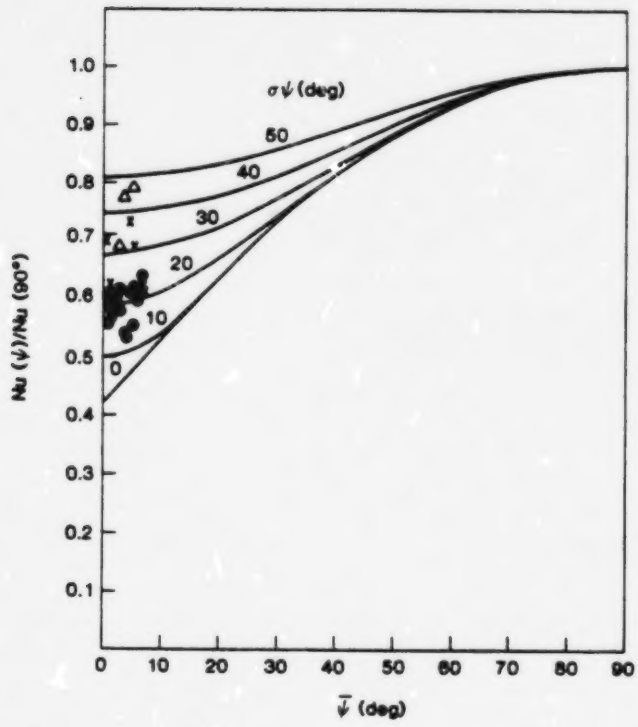
V_{90} = Wind component perpendicular to conductor z-axis.

K_h = Height-Dependent Wind Sheltering Factor.

K_z = Spatial Variability Factor.

V_{wind} = Measured wind speed in any direction.

θ = Angle of wind to conductor z-axis.



● experimental results, σψ = 15–24 deg.,
X σψ = 25–34 deg., Δ σψ = 35–44 deg.
—— theoretical analysis.

Figure 1: The Effect of the Mean Wind Angle, $\bar{\psi}$, and its Standard Deviation σ_ψ on the Convective Heat Loss $Nu(\psi)$ from a Stranded Conductor.

From Morgan/5/.

When a minimum wind speed of 4 km/hr, a wind angle of 20°, the sheltering factor $K_h = 0.7$ and the spatial factor $K_s = 0.8$ are used in Equation 1, we obtain a perpendicular wind velocity V_{90} of 0.9 km/hr. In the experiments at Essa, we found that low-wind conditions resulted in less-than-predicted temperature rise. The conductor temperatures observed suggest that the effective minimum daytime wind velocity V_{90} may be as high as 2 km/hr in our test span. Figure 2 shows this. The 1-hour OOLM predictions for a typical three-day period are obtained using assumed minimum wind speeds V_{90} of 0, 0.9, 1.8 and 2.7 km/hr. A minimum daytime V_{90} of 1.8 km/hr gives the best estimates in most cases. We consider our test span to be unsheltered. If the relationship between sheltered- and unsheltered-span cooling is accurately reflected by a K_h factor of 0.7, then the corresponding minimum sheltered wind velocity could be as high as V_{90} = (0.7 * 1.8 km/hr) = 1.3 km/hr. This possibility should be checked by long-term measurements in a variety of sheltering conditions.

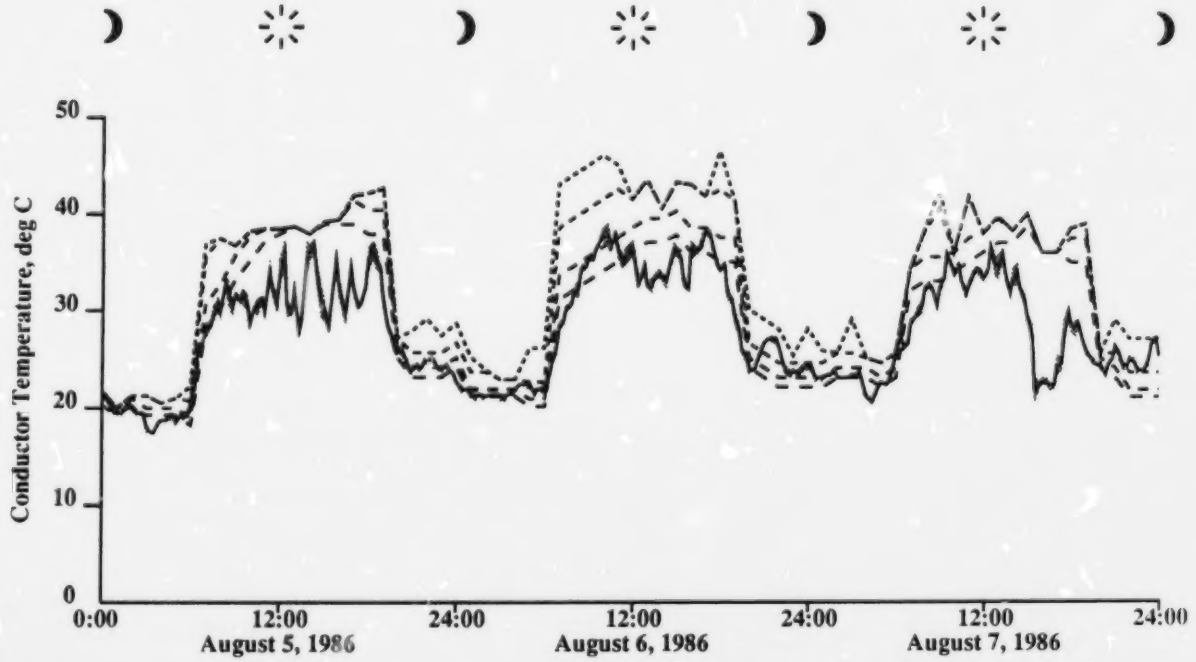


Figure 2: Unsheltered Test Span Observations and Predictions for August 5-6-7, 1986.
Solid Line Shows Observed Conductor Temperature.
Dashed Lines Show Influence of Minimum Wind-Speed Assumptions.

..... **V_{90} > 0.0 km/hr**
--------- **V_{90} > 0.9 km/hr**
- - - - - - - **V_{90} > 1.8 km/hr**
- - - - - **V_{90} > 2.7 km/hr**

CONCLUSIONS

This summer, the conductor temperature was over 40° C on at least ten days when a current of 260 A was circulating. A maximum of only 43° C occurred, compared with 47°C in the summer of 1985. While higher ambient temperatures of up to 34°C were observed in 1986, the hot periods were always accompanied by high wind speeds, leading to lower conductor temperature rise above ambient.

The use of predicted weather data from the Out-of-Limits Monitoring program led to conservative over-estimates of conductor temperatures on 23 of 36 days reported. Predicted temperatures were too low on only 5 days. This bias is due mainly to the reduction factors for wind angle, sheltering and spatial variability that are applied to wind speeds. A minimum perpendicular wind velocity V_{90} of 1.8 km/hr gives the best agreement between OOLM estimates and our field observations. This V_{90} would result from a minimum wind speed of 4 km/hr, a wind angle of 32°, a sheltering factor K_h of 1.0 and a spatial variability factor K_s of 0.8.

RECOMMENDATIONS

The practice of assuming a 4 km/hr minimum wind speed should be examined further, since wind behaviour at low speeds is poorly modeled in existing calculations. The standard deviation of wind direction contributes additional cooling. It is also likely that sheltering factors vary with wind speed and solar input. An improved model of low-wind cooling behaviour should be developed.

The wind direction standard deviation should be determined in sheltered and unsheltered conditions as an input to this new model. Further theoretical and experimental support for increasing the effective wind direction under low-wind conditions would raise summer-ampacity currents.

Approved:

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Submitted:

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Transmission and
Special Projects Section

WAC:wac

REFERENCES

1. "Calculation of Continuous and Emergency Conductor Ampacities", M. Cenanovic, Ontario Hydro Research Division Report 74-192-H

2. "Overhead Conductor Ampacity Studies I: Essa Test Line Instrumentation", W.A. Chisholm, Ontario Hydro Research Division Report 85-230-H.

3. "Overhead Conductor Ampacity Studies II: Essa Test Line Results, Summer 1985", W.A. Chisholm and J.S. Barrett, Ontario Hydro Research Division Report 86-91-K.

4. Transmission Design Methods Number 9, "Ampacity of ACSR Transmission Lines", November 1972.

5. "The Real-Time Heat Balance for Overhead Conductors", V.T. Morgan, Proceedings of Seminar on Real-Time Ratings of Overhead Conductors, May 21, 1986, Atlanta, Georgia.

APPENDIX 1: FIELD OBSERVATIONS AND OOLM PREDICTIONS

Each Figure, A1-A12, shows three days of observations. Solid lines show measurements of the incident solar radiation, the vector sum of horizontal and vertical wind speed, the ambient temperature at the conductor height and the conductor temperature. The line current was a constant 260±10 A and is not plotted.

The grey areas appearing around the measured data indicate the 15-minute standard deviations. These uncertainties are large for many solar and wind observations, and small for temperature data.

Dashed lines in Figures A1-A12 show the OOLM 1-hour and 5-hour predictions of wind speed and ambient temperature. The existing practice for solar input assumes that the sun provides a constant 814 W/m^2 to the conductor. This model was modified by turning the sun on at 6AM and off at 8PM.

With predicted values for ambient temperature, wind speed and solar input, the Transmission Design Method for ampacity calculations/4/ was used to calculate 1-hour and 5-hour predicted conductor temperatures. This method predicts conductor temperatures with good accuracy/3/ when the weather conditions at the site are used as input. The usual values of spatial factor K_s = 0.8, sheltering factor K_h = 0.7 and wind angle θ = 20° were applied to the OOLM wind-speed predictions using Equation 1. No "minimum wind speed" limits were used. The predicted temperatures are plotted as dashed lines in the bottom graphs of Figures A1-A12.

The OOLM-based predictions of conductor temperature are too high on 23 days, within 2 C° on 8 days and too low on 5 days. There are two main causes for this conservative bias. First, the test span is somewhat unsheltered, with the nearest trees being 50-70m to the east. This means that the sheltering factor K_h could be greater than 0.7. Second, the test line runs north-south and the usual wind direction is east-west, so the assumption of a 20° wind angle is low.

The conservative bias of the OOLM-based predictions can be reduced. If a minimum perpendicular wind velocity V_{90} of 1.8 km/hr is assumed, then the predictions are too high on 16 days, accurate on 14 days and too low on 6 days. The six days on which predictions are too low are July 14, July 17, July 20, July 29, August 9 and August 11. On each of these days, wind-speed assumptions had little influence because ambient temperature forecasts were low.

Condition	K_h	K_s	V_{wind}	θ	$\sqrt{0.05+0.95\sin^2\theta}$	V_{90}
Previous	0.7	0.8	4 km/hr	20°	0.401	0.90 km/hr
Validated 1986	1.0	0.8	4 km/hr	32°	0.563	1.80 km/hr
Inferred	0.7	0.8	4 km/hr	32°	0.563	1.26 km/hr

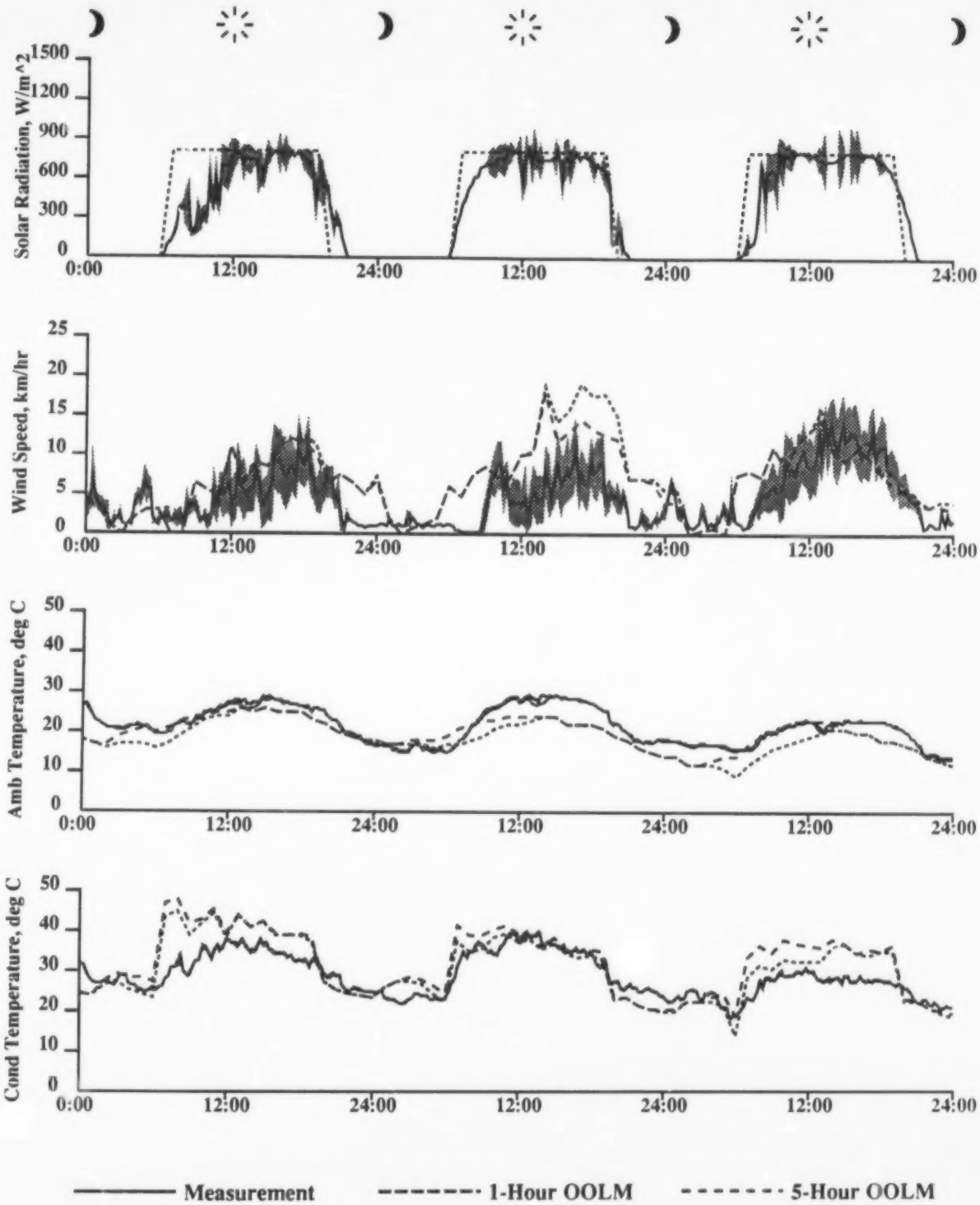

Figure A1: Field Measurements and OOLM Predictions, July 8-9-10, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

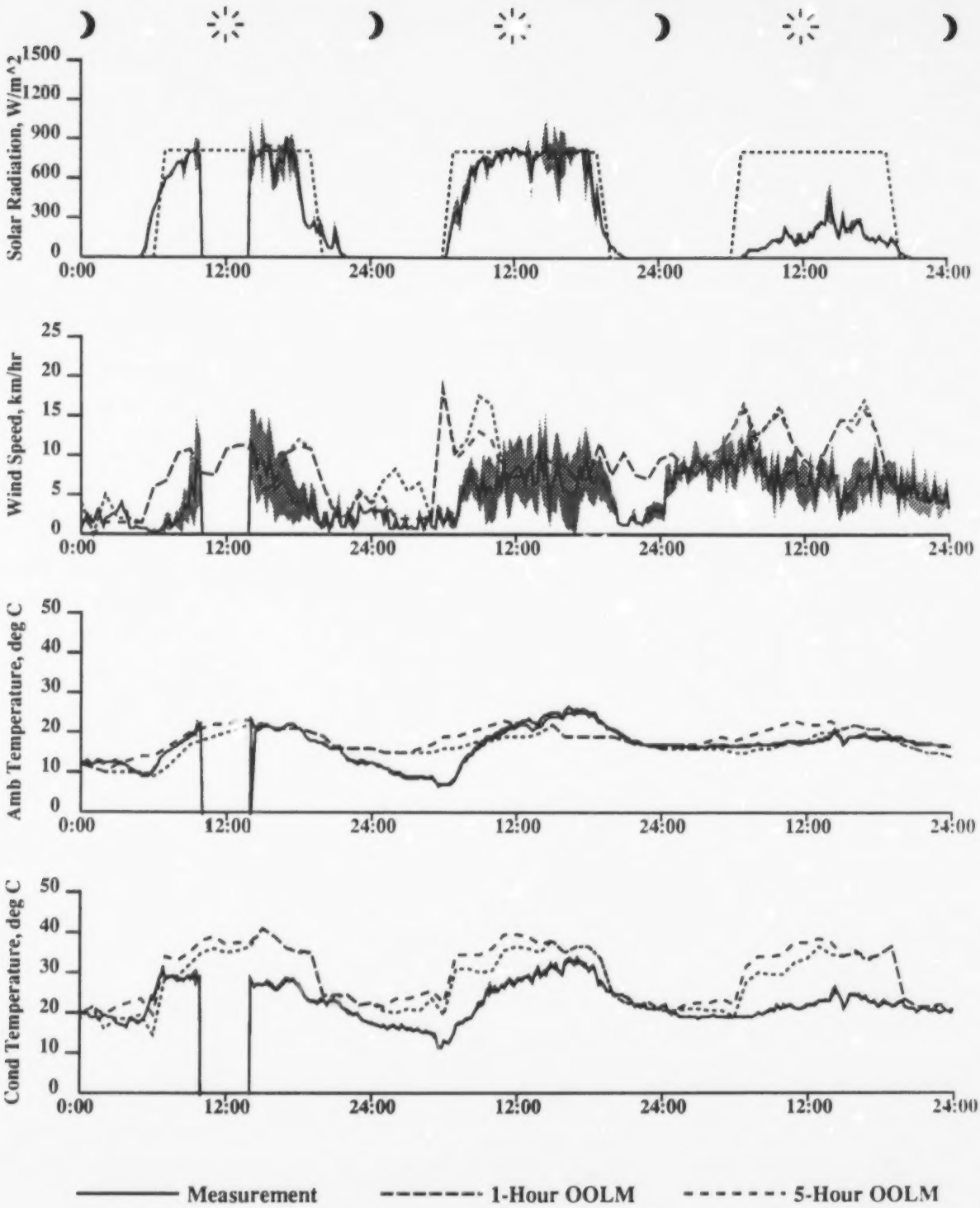

Figure A2: Field Measurements and OOLM Predictions, July 11-12-13, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

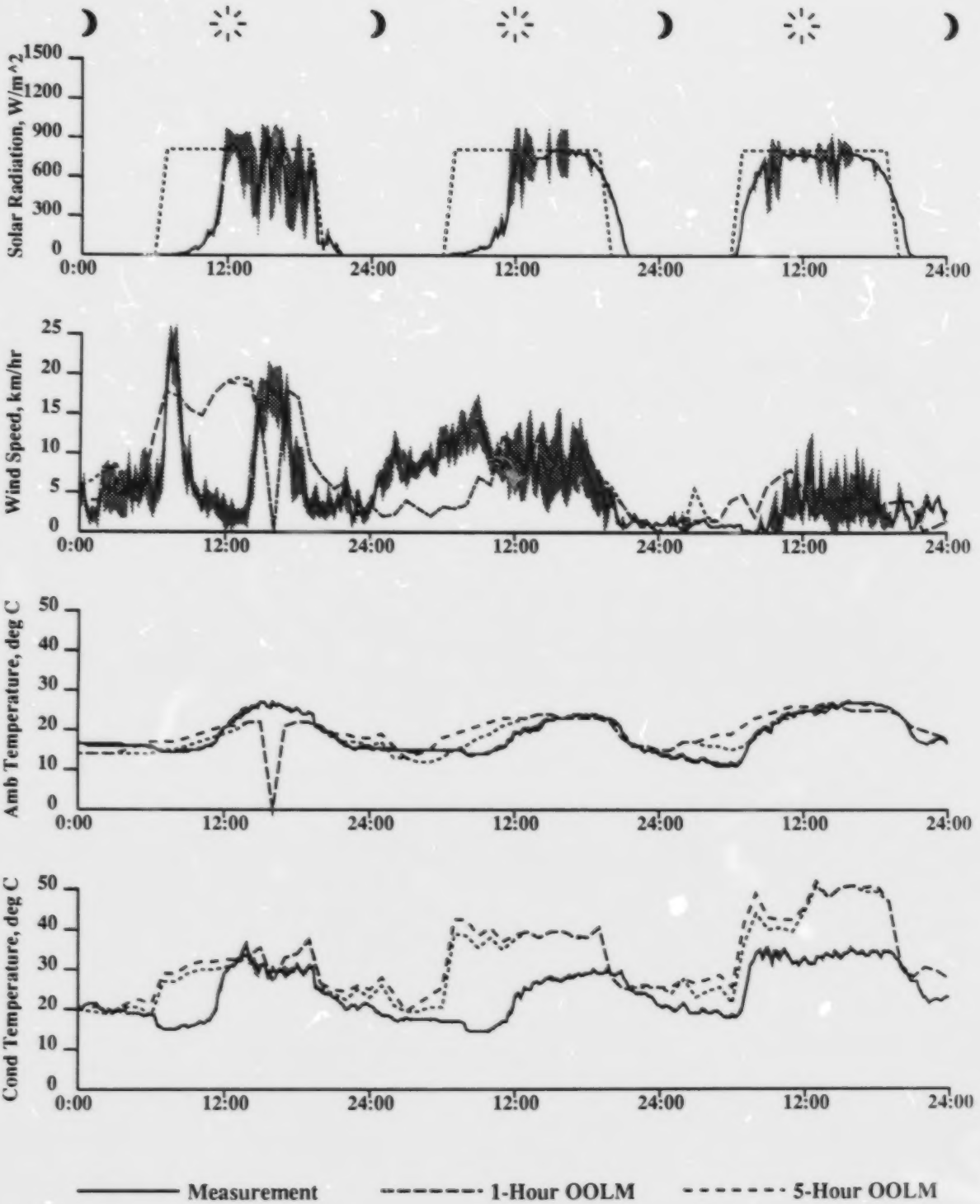

Figure A3: Field Measurements and OOLM Predictions, July 14-15-16, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

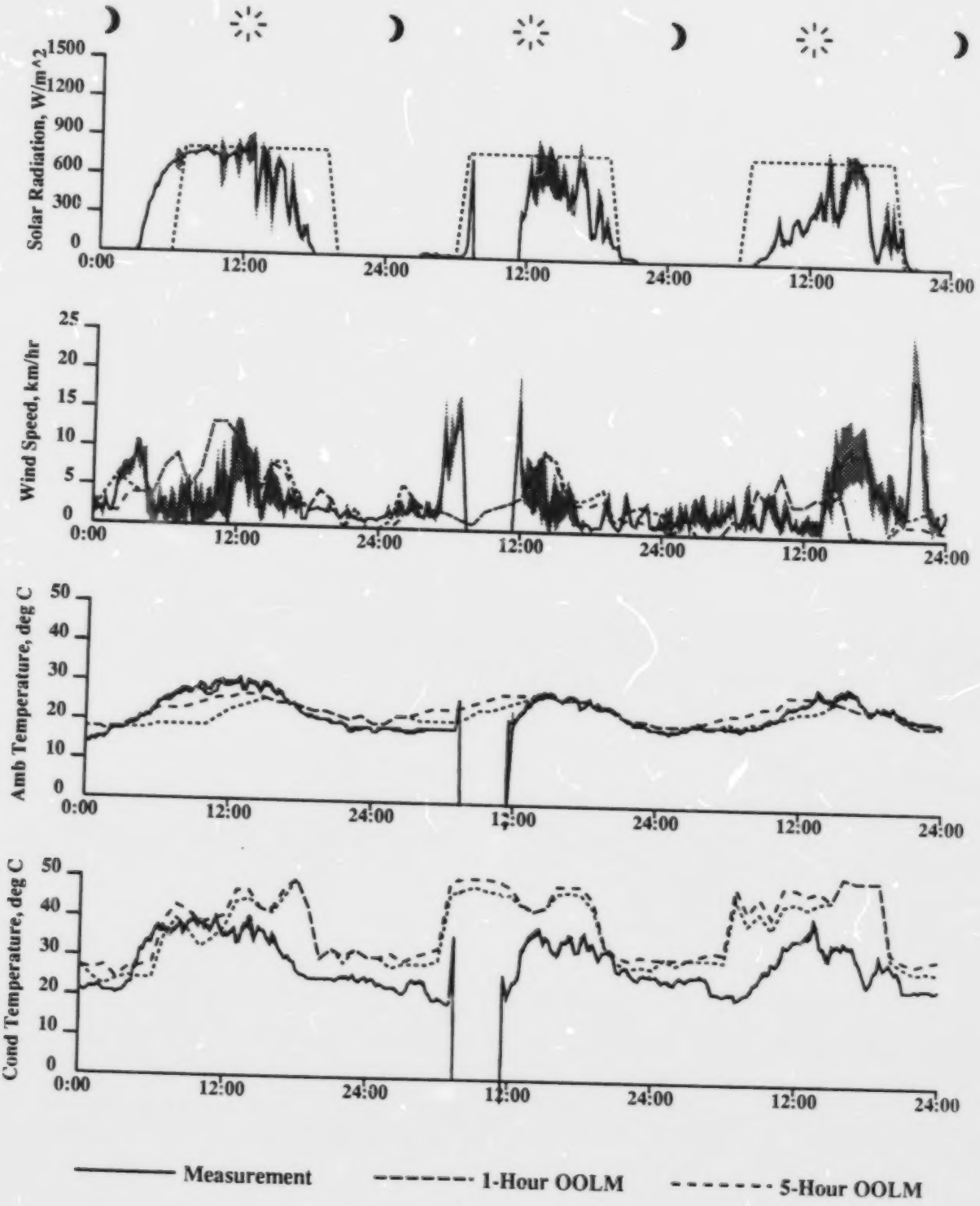

Figure A4: Field Measurements and OOLM Predictions, July 17-18-19, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

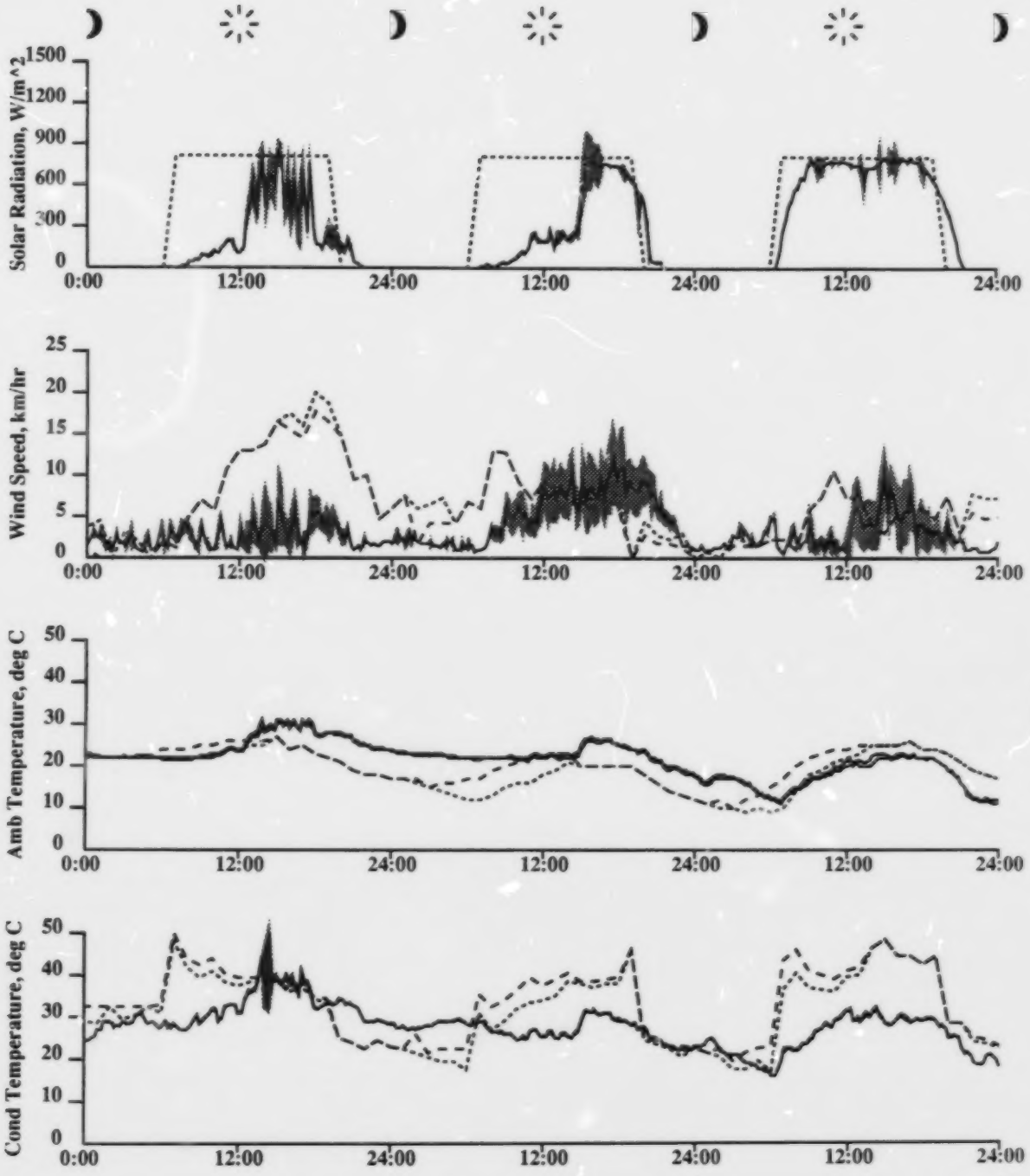

Figure A5: Field Measurements and OOLM Predictions, July 20-21-22, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

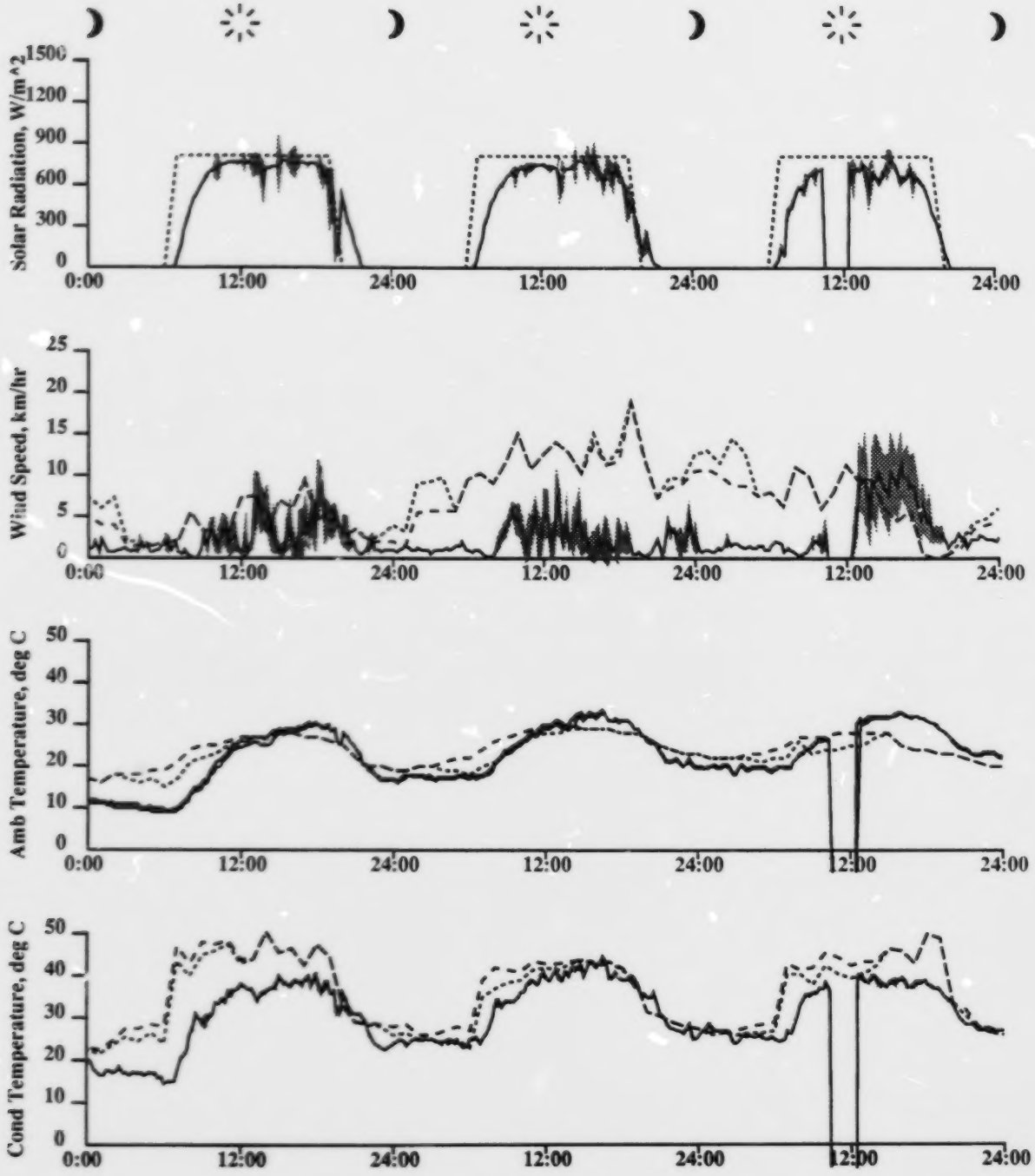

Figure A6: Field Measurements and OOLM Predictions, July 23-24-25, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

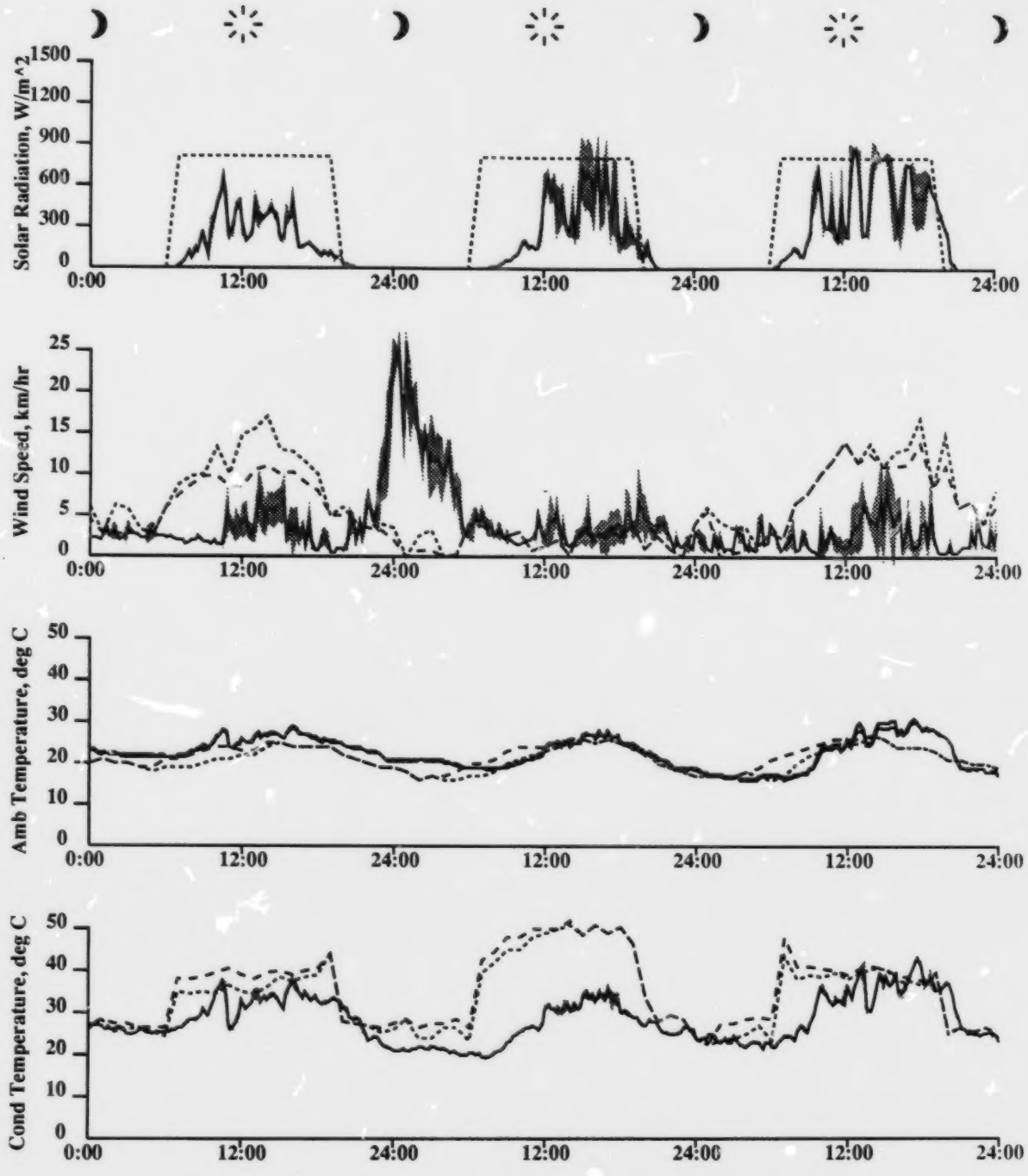

Figure A7: Field Measurements and OOLM Predictions, July 26-27-28, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

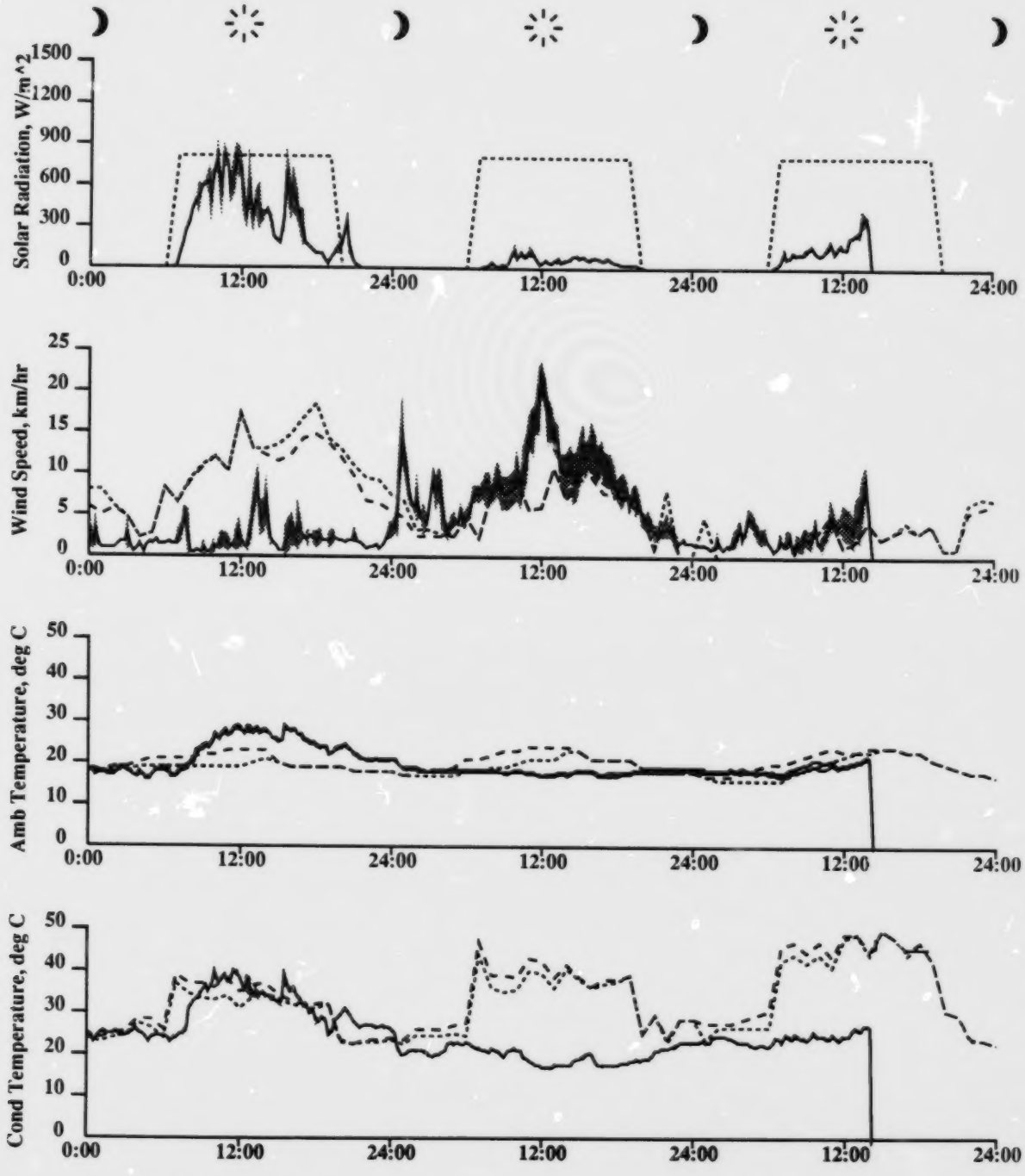

Figure A8: Field Measurements and OOLM Predictions, July 29-30-31, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

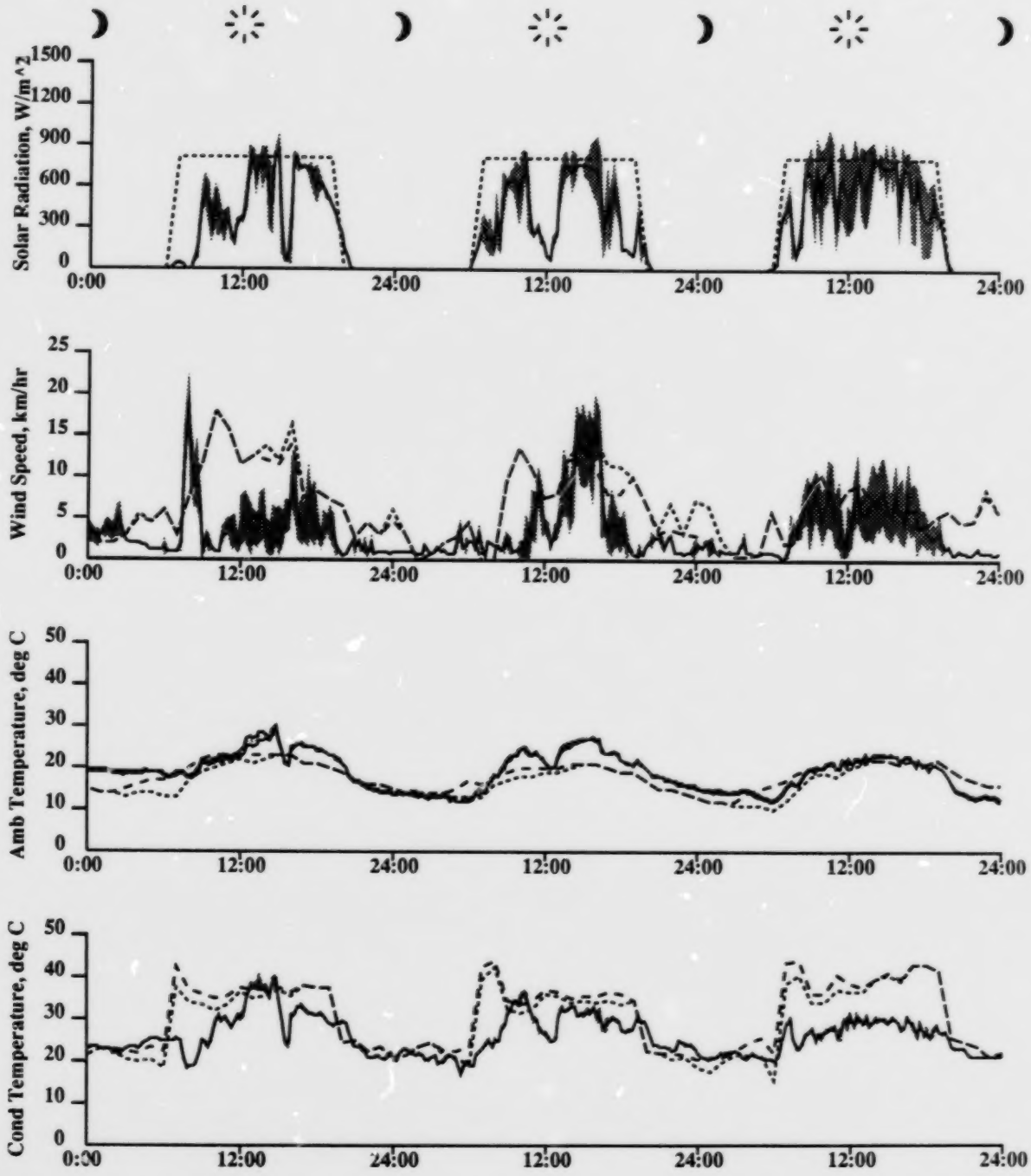

Figure A9: Field Measurements and OOLM Predictions, August 2-3-4, 1986

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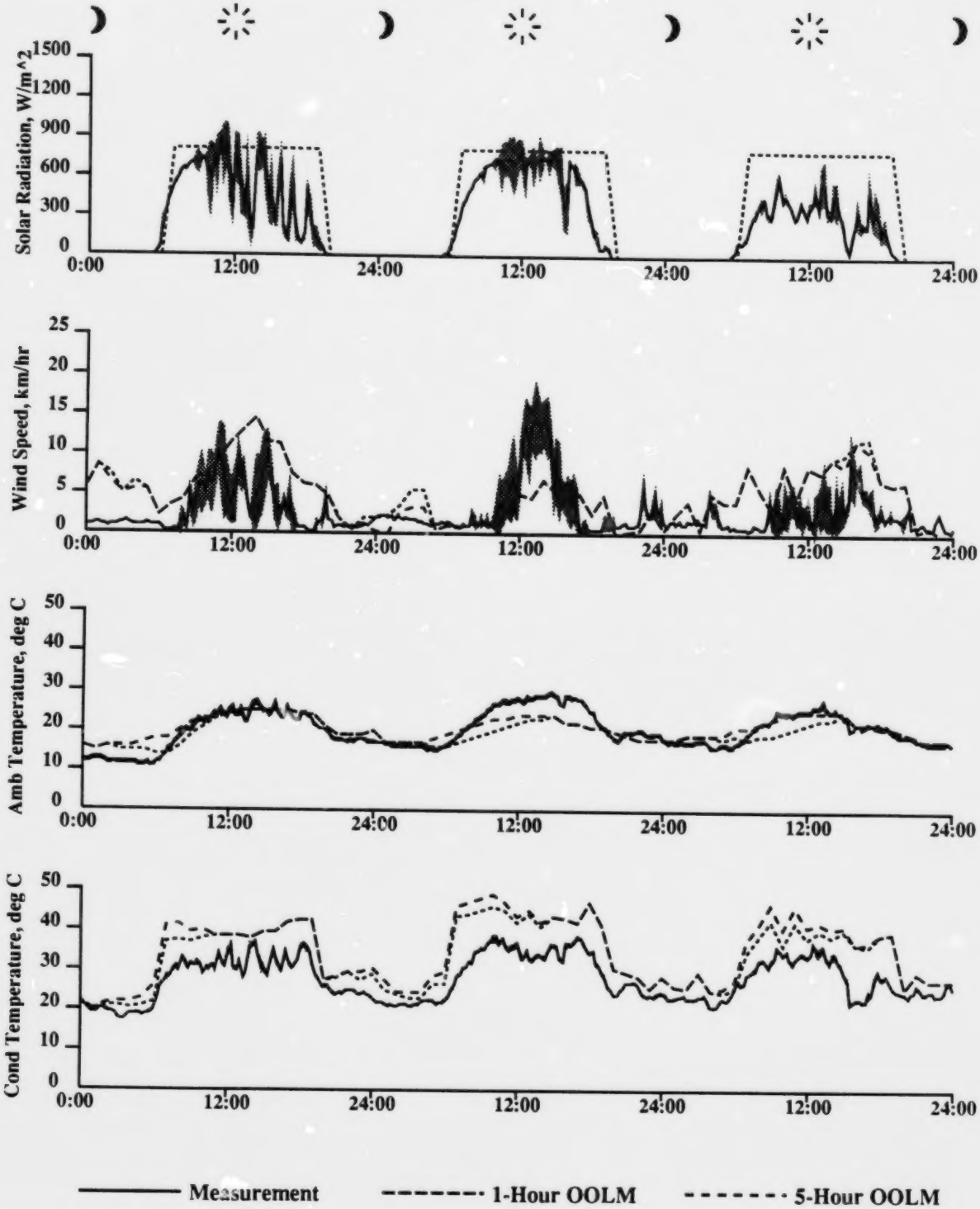

Figure A10: Field Measurements and OOLM Predictions, August 5-6-7, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

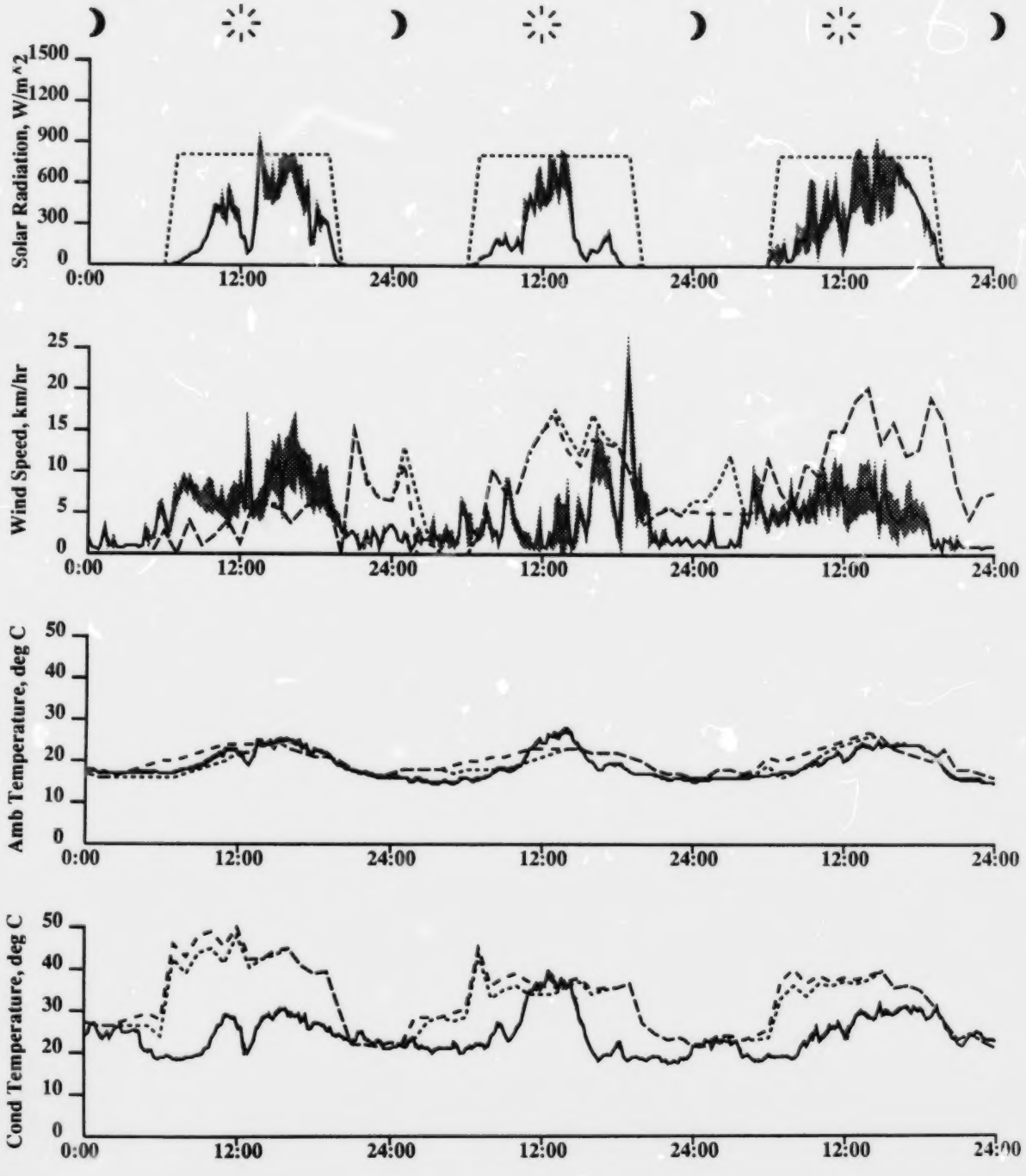

Figure A11: Field Measurements and OOLM Predictions, August 8-9-10, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

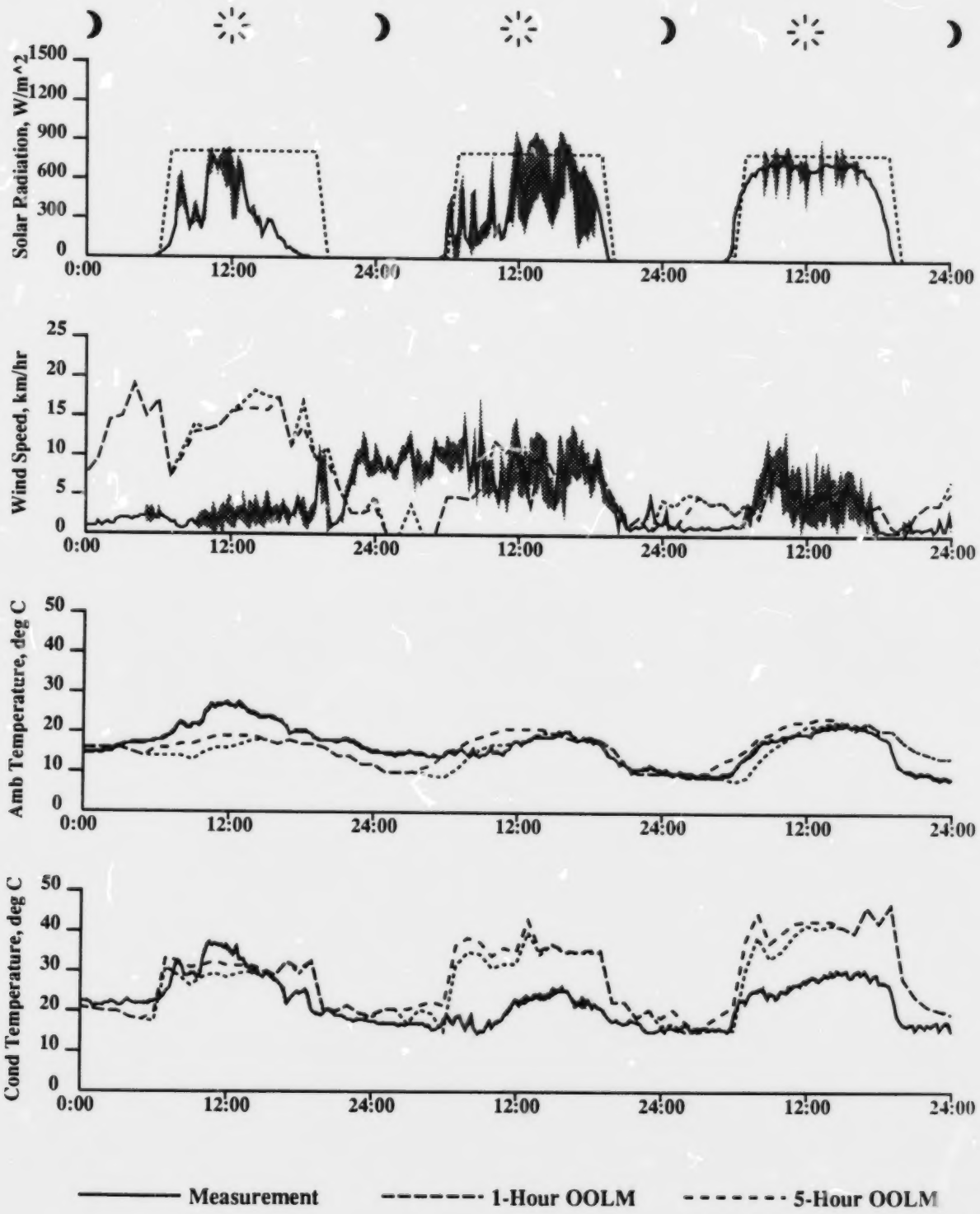

Figure A12: Field Measurements and OOLM Predictions, August 11-12-13, 1986

Line Current = 260A; K_h=0.7; K_s=0.8; θ = 20 degrees; Minimum V_{90} = 0 km/hr.

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